Discussion of the protection retrofit principle of the earthquake damaged building site and introduction of an example

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SUMMARY:
This paper discusses the principle of the protection retrofit of the earthquake damaged building site. The function of the earthquake damaged building site is retaining earthquake damage phenomenon for scientific investigation and tourist attractions, protection retrofit principles, the lowest disturb to the damage phenomenon, keeping the site structure stable and preventing the site from collapse during frequent earthquake. The design reliability of the protection retrofit for the damaged buildings may be slightly lower than that of the new structures. Damage level of the structural elements of the site should be estimated and considered during the design of the protection retrofit components. A typical protection retrofit design of the earthquake damaged site, Comprehensive building of White Deer middle school, Sichuan, China, is presented as an example. The steel components were used for the retrofit. Internal force of the undamaged structure was analysed, earthquake damage indexes and bearing capacity reduction factors of all the masonry walls were estimated based on the damage phenomenon. The design values of the internal force of the retrofit components were calculated. The H-shape steel columns and X-shape braces were applied for reinforcing the longitudinal walls, the X-shape angle steel braces were used for the cross walls' retrofit. All the retrofit components, together with the masonry walls were connected with the ring beams of the original structure, composing a steel-masonry composite structure, carried the gravity and the possible earthquake.

Keywords: protection retrofit, earthquake damage, building site

1. GENERAL INSTRUCTIONS

Sudden, unexpected does the earthquake come and go, but lasting pain are left for us. Too much grief and loss has the earthquake brought to the society to remind us the importance of the earthquake disaster mitigation. So sometimes after a large earthquake, typical earthquake damaged sites are preserved to commemorate the dead people, to warm society the importance of the earthquake disaster mitigation, to exhibit seismic geological changes and engineering damage, also to remind engineers the experiences and lessons which should be learned from the disasters.

For the commemoration of the Richter 7.8 earthquake occurred in Tang Shan China 1976, an earthquake ruins memorial park was built in 2008 at the epicenter of the earthquake. After Chi-chi earthquake, the seismic ruins of Guangfu secondary school at Taichung city were preserved, with an earthquake scientific exhibitions, together forms the '921 earthquake education park'. After the Kobe earthquake in 1995, parts of the destroyed wharf were preserved in the meriken-park of Kobe city, and the tanshui cho earthquake memorial park was built at Hyogo prefectures, which exhibit the seismic disaster and disaster prevention systematically. After WenChuan earthquake in China 2008, some earthquake damaged sites were also preserved as the commemoration.

For an existing earthquake memorial park, geological changes and seismic damaged building sites are the most intuitive earthquake disaster exhibits. However, the building sites were often damaged seriously, sometimes even like the ruins, which can't resist the erosion of the years and gradually decomposed without protection. Nowadays, there are few kept seismic building sites in TangShan, and even the sites remained are already dilapidated. The earthquake damaged sites in Guangfu secondary school at Taichung city are retrofitted and sheltered, and preserved relatively good. Some of the building sites damaged in the WenChuan earthquake in 2008 are now eroded significantly; some earthquake damage phenomenon is even gradually disappearing. Furthermore, some building sites are facing with increasingly high risk of collapse, which obviously threaten the protection and the preservation value of the earthquake damaged site.

So the earthquake damaged site with typical seismic damaged phenomenon is to be protected and be retrofitted, for the purpose of long time preservation. Thus the earthquake damaged phenomenon can be preserved in a long period, and can contribute to the publicity and popular science of earthquake disaster mitigation. However, the protection retrofit of the earthquake damage site is quite deferent from the regular engineering retrofit that the sites have always been damaged seriously, and the retrofit project should preserve the damage phenomenon as much as possible, and the safety of the site's visitors also should be ensured. Protection retrofitting of the earthquake damaged site is such a special engineering that seldom technical references are recorded, so this paper discusses the principle and method of the protection retrofit of the site. The protection retrofit design for a damaged building site after Wenchuan earthquake is also presented. These can be served as the reference of the similar engineering.

2. THE PRINCIPLES AND THE PURPOSE OF THE SEISMIC DAMAGED BUILDING SITE'S PROTECTION RETROFIT:

2.1. Selection of the earthquake damage site to be preserved

It is preferred that the site, which contains both the typical geological earthquake damage and typical building structure seismic damage can be retrofitted and preserved. Fault rupture or ground fissures can be the typically geological earthquake damage, and the building site structure can be seriously damaged or even partial collapsed, while still can be retrofitted to stable bearing, preventing from block falling, and a certain degree of durability. Thus the earthquake damage site can reflect the cause and the result of the earthquake disaster clearly and intuitively, and the building site can be retrofit appropriately to ensure the safety of the close visitors.

2.2. Requirement of the protection retrofit of the earthquake damaged building site

Since the building site retrofitted is not for regular use, the requirement of the protection retrofit of the site is quite different from the ordinary building structures, described as follows:

Reservation of the damage phenomenon: It must be well considered before the retrofit design whether the retrofit structure will block the damage phenomenon. A good retrofit structure scheme should have minimal impact on the appearance of the damaged site. When it is inevitable that the retrofit structure connected to the site structure changes the appearance of the site, trade-offs can be made according to the visit requirement of the site. For example, for a mainly peripheral visit building site, the retrofit structures can be arranged inside the building.

Insurance of the vertical load-bearing stability of the site: Despite the damaged site may be stable temporarily after the earthquake, the severe structural damage often indicates that the site is in danger of further server damage or even collapse. The damaged structure and maintenance are not able to protect the site from the raining erosion, the environment and the years. All these will threaten the stability of the site structure; and even cause the overall collapse of the site. So ensuring the retrofitted site structure stable under the vertical load is the basic requirement of the protection retrofit.

Preventing the site from collapse or local drop under frequent earthquake of the design reference period: Considering that the retrofit purpose of the site is to preserve the damage phenomenon and to ensure the safety of the visitors, which is quite different from the design of ordinary building structures, the possibility of causing casualties and property losses of the site when encountering an earthquake is far less than it of the ordinary building. So we recommend that the seismic design principle of the protection retrofit of the site can be set as preventing the site from collapse and local drop under the frequent earthquake during the service life of the site.

Insurance of the durability of the site: Serious damage of the site causes more exposure of the structure components and the building materials to the natural environment, also with the damage of the waterproof and thermal insulation, the durability of the site can be significantly weakened, which makes the damage phenomenon deteriorated slowly and makes the structure of the site degraded gradually. So durability of the site should be ensured by the protection retrofit to maintain the safety and the damage phenomenon of the site.

2.3. Protection retrofit design of the earthquake damaged building site

Based on the principle mentioned-above, proposals to the retrofit design of the site are described below:

Retrofit structure type: Since the site to be protected is often damaged severely, significantly decreasing of the structural bearing capacity has occurred; it is irrational, or even dangerous to add excessive weight to the site structure. Furthermore, smaller cross-section retrofit component means slighter changes to the damage phenomenon of the site. So the steel structure is recommended for the protection retrofit of the site.

Material strength value and load value for the retrofit design: The material strength of the site should be detected for the retrofit design, and the design load value should be accordance with the actual load, rather than the design values for ordinary structures.

Assessment and utilization of the remaining bearing-capacity of the site structure: Although the site may have suffered severe damage, there are still stiffness, vertical bearing capacity and lateral bearing capacity remaining, which should be reasonable assessment in the protection retrofit design. Ignoring all the remaining stiffness and bearing capacity of the site structure will result in an irrational retrofit design which is overly conservative and different from the real structural properties of the site. So the seismic damage degrees of the structural components and the whole structure system should be reasonable evaluated and be as the basic conditions of the retrofit design.

Design of the retrofit components: It is appropriate for the retrofit components to be connected to the site structure, which both provides support for the site structure and forms a combination bearing system. The connecting construction should be designed coordinating with the site structure component's damage level. Then mechanical model according with the actual loading state of the retrofitted site structure can be established, the internal force analysis and the retrofit can be carried out following the conventional structural analysis and design methods.

Conceptual design and connection measures: The mean purposes of conceptual design and connecting measures of the protection retrofit are connecting the retrofit components to the site structure and together forming a whole structural system, amending the seismic disadvantages of the site structures(for example, adjusting the local stiffness of the retrofit structure by adding retrofit component to decrease the structural irregularity and diminishing the reverse effect of the site structure), and tying firmly the components and appendages which are suspected falling down.

Durability design: Since the site was server damaged, amounts of damaged components are exposed to the natural environment; and the using requirement of the site is only preserving the seismic damage phenomenon, therefore the durability requirement of the protection retrofit can also be lower than the ordinary building. Thus the recommending durability design of the protection retrofit can be descried as follows: retrofit component should be constructed with durability (for example, covering the steel retrofit components with anticorrosion coating); the poor durability of damaged components of the site structure should be taken into account during the retrofit design (such as combining the mechanics degradation both by earthquake damage and by environmental erosion together during the design procedure); the waterproof of the site should be restored and the regular maintenance should be sustained, or new waterproof facility should be built, such as a shelters for the whole site.

2.4. Retrofit construction of the building site

Since the site may have severe damaged or even be at the verge of collapse before retrofitted, barbaric construction operation may cause further damage or even collapse to the site structure. So construction program should be carefully studied with the damage features of the site taken into account. Temporary support and banding measures should be adopted during construction operation which may threaten the site structure, or lead to components or appendages falling or secondary damage of the site. The construction operation must be implemented very carefully to ensure safety.

3. AN EXAMPLE OF THE EARTHQUAKE DAMAGED BUILDING SITE PROTECTION RETROFIT

3.1. Overview

Comprehensive building of White Deer middle school, White Deer town, Pengzhou, Sichuan Province, China, is a 4 storey brick-concrete structure, which was designed and built in 1985. The thickness of the longitudinal wall is 370mm in storey 1 and storey2, 240mm in storey 3 and storey 4 respectively; the thickness of the cross wall is 240mm in all the stories. The floors and the roof were formed by the precast prestressed hollow slab. The basis of the building was also masonry brick strip foundation. Fig.1 shows several aspects of the sight for the building, and Fig.2a) shows the plan of the first storey.

In the Wenchuan earthquake occurred on May 12th. 2008, a ground fissure passed through the middle ground between the comprehensive building and the classroom building (a 3 storey brick-concrete structure), which was built in 2005. The height difference between the two buildings was changed due to the strong ground motion from 0 to about 3m high. The comprehensive building was severely damaged, locally near-collapse, while the classroom building survived with its structure basically well-remained, as shown in Fig.1.

The well-remained state, so closing to the great ground fissure and the sharp contrast between the two buildings make the classroom building famous as 'the strongest classroom building of 5.12 Wenchuan earthquake'. Now the middle school is relocated away, the tow buildings are of idle. The comprehensive building, severely damaged but still stable bearing, exhibits the typical seismic damage phenomena of the brick-concrete structures widely used in China; while the classroom building, designed with more reasonable seismic measures, shows how important an excellent seismic deign could be for a structures; together with the great ground fissure and the 'famous' of the classroom building, makes it a suitable choice for the site to be preserved as a earthquake damage site. Now the local tourism development department is planning to build a science exhibition and earthquake experience equipment center near the site, altogether forms a earthquake memorial park. Commissioned by the local tourism development department, we carried out the protection retrofit design for the comprehensive building site.

3.2. The earthquake damage and retrofit scheme of the comprehensive building site

Structural elements between C-axis and E-axis in Fig.2a) were severely damaged, while the elements between A-axis and B-axis were slightly damaged. The cross walls of the lower storey were damaged more severely than that of upper storey; longitudinal walls of storey 3 and storey 4 were damaged severely, parts of the walls at storey 4 were nearly collapse (Fig.1g)), while the longitudinal walls of storey 1 and storey 2 were damaged slighter than that of the upper storey. Most of reinforced concrete stairs, reinforced beams and precast prestressed concrete slabs survive basically well-remained, except relative slippage occurred between some precast slabs.

a) Overview of the site

b) External view of the comprehensive building (1)


c) External view of the building (2)


d) External view of the building (3)

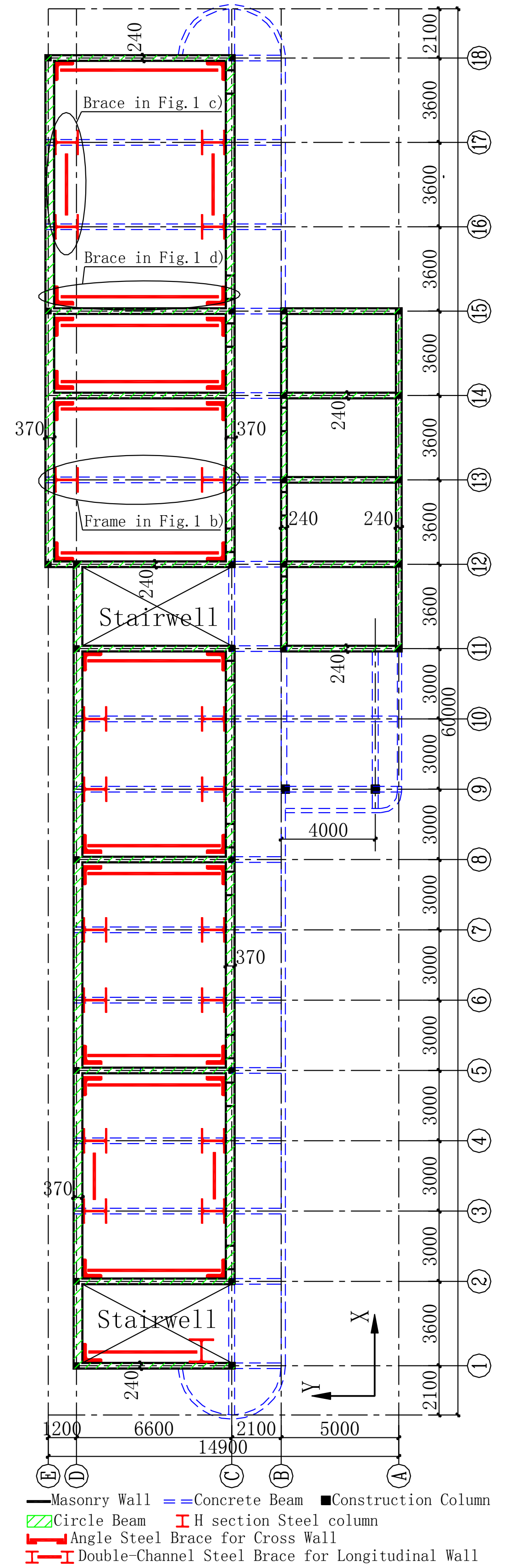
e) Internal view (1)

f) View of the classroom at storey 4 (1)

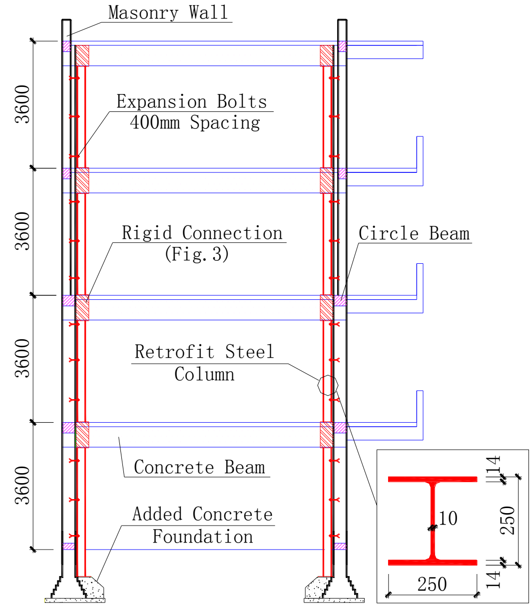
g) View of the classroom at storey 4 (2)

Fig.1 Overview of White Deer Middle school earthquake damaged site and typical damage appearances of the comprehensive building

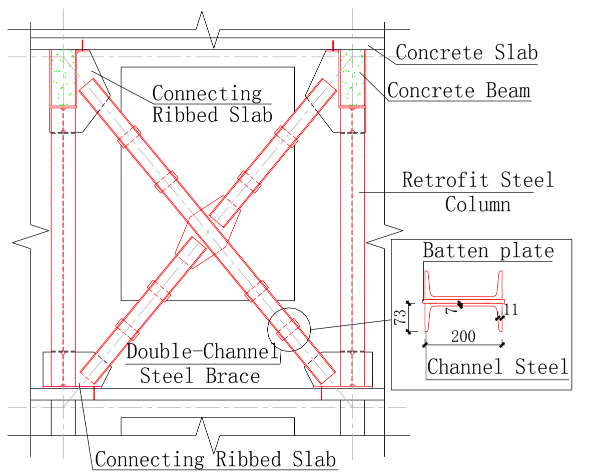
The components between C-axis and E-axis in Fig.2 were retrofitted based on the seismic damage distribution of the building. Steel-masonry mixed bracing-frame structure was used for the retrofitting. Layout of the retrofitting components of storey 1 is shown in Fig.2. Since some vertical walls, especially the one between windows, were damaged significantly, which may threaten the bearing capacity of the structure, H-shaped steel columns were assigned at both ends of the beams crossing the vertical walls.



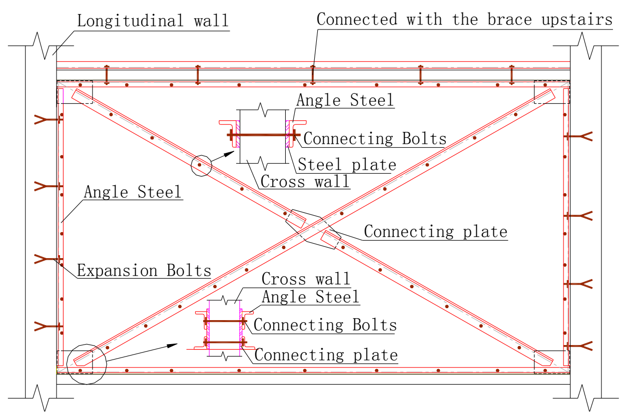
a) Structural plan and layout of retrofit components



b) Retrofit steel columns and concrete beams frame



c) Steel brace for longitudinal wall



d) Steel brace for cross wall

Fig.2 Structural plan and retrofit components layout of the comprehensive building site's first storey (mm)

The steel columns and the beams were camped connected together and forms several frames as shown in Fig.2, which undertook the vertical load and Y-direction horizontal earthquake. The frames were connected to the adjacent vertical walls using expansion bolts to tie the damaged vertical walls with the retrofit structure. The 4 X-shaped steel braces shown in Fig.2c) were assigned in all storeys, together with the vertical walls, bearing the X-direction earthquake. Under all steel columns concrete foundations were designed. Although some of the cross walls were also damaged significantly, less openings make the cross walls more stable under the vertical load. Main objective of retrofitting the cross walls was to improve the horizontal bearing capacity and stability of the walls. Thus welded angle steel X-shape braces shown in Fig.2b) were adopted. For most cross walls in each storey, two braces were arranged at the two faces of each wall (for the end cross walls and stairwell cross walls, one brace was designed for each wall), connected with the wall together by bolts to make it retrofitted.

3.3. Internal force estimate and strength check of the retrofit components

Constant load of the roof and the floor was designed for 2.78kN/m^2, and the live load for 1.5kM/m^2 according to the load estimate of the site. Horizontal earthquake coefficient value for strength checking of the retrofitted structure is set as 0.16, which is roughly equivalent to the earthquake peak acceleration of 70cm/s2, corresponding to the common earthquake action of intensity 8 according to the Code for seismic design of buildings of China[1]. Strength of mortar, bricks and concrete of the site was all designed with design value detected.

The frame shown in Fig.2b) was considered conservatively as bearing the entire vertical load and the entire horizontal earthquake action of the structure parts under jurisdiction of the concrete beams. Thus the internal force of the frame can be calculated by base shear method, and the strength of components and the connections can be checked by regular design methods. After checking, HW250a was selected for the steel column, and the connection between steel and concrete beams are designed as Fig.3.

The retrofit braces were designed as follows: fist, elastic internal force analysis of the undamaged structure was carried out. According to the Code for design of masonry structures of China [2], every masonry wall's vertical bearing capacity and horizontal bearing capacity, internal force of gravity and internal force of seismic action are all calculated. The horizontal bearing capacities and the internal forces of seismic action of the walls of storey 1 are shown in Fig.4. Then, the seismic damage and the reduction of horizontal bearing capacity for the walls are identified: according to the definition of masonry component seismic damage level [3], seismic damage index for masonry walls are defined empirically in table 3.1, and the relationship between reduction of horizontal bearing capacity and damage index of the masonry wall was conservatively estimated by empirics, as shown in Fig.5. Thus both the damage indexes and the reduction of horizontal bearing capacity of the retrofitted walls can be evaluated, as shown in Fig.4. Subtract the remaining horizontal bearing capacity from the internal horizontal force of each masonry wall, design internal force of the retrofit component for each wall can be get, the internal forces calculation of several walls in storey 1 are shown in table 2. Thus the bearing capacity of the retrofit components can be checked as follows: the summation internal force of X-direction braces in one storey can be calculated by adding the retrofit internal forces of all the longitudinal walls in one storey; the brace for each cross wall can be checked according to the retrofit internal force of the cross wall directly. By this method, cross-section selecting and internal force checking of every retrofit brace component are carried out. For example, the retrofit brace for cross wall of axis 13, storey 1 are designed as Fig.2d).

It should be noted that since there were quite a few of cracks discovered between the precast slabs, the seismic damage and stiffness degradation of the diaphragm were difficult to evaluate. So the Y-direction horizontal earthquake action of the structure was fully added to the cross walls' retrofit braces conservatively, while parts of the same earthquake action were already taken into account during deign of the frames shown in Fig.2b).

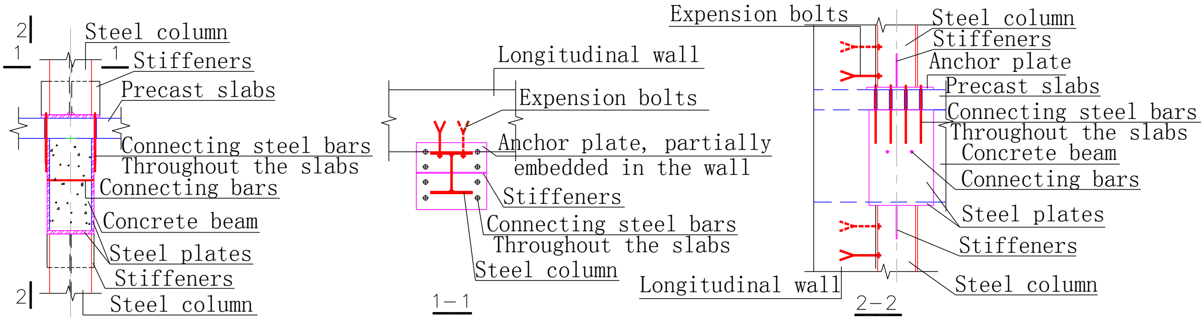


Fig. 3 Connection of the retrofit steel columns and the concrete beam

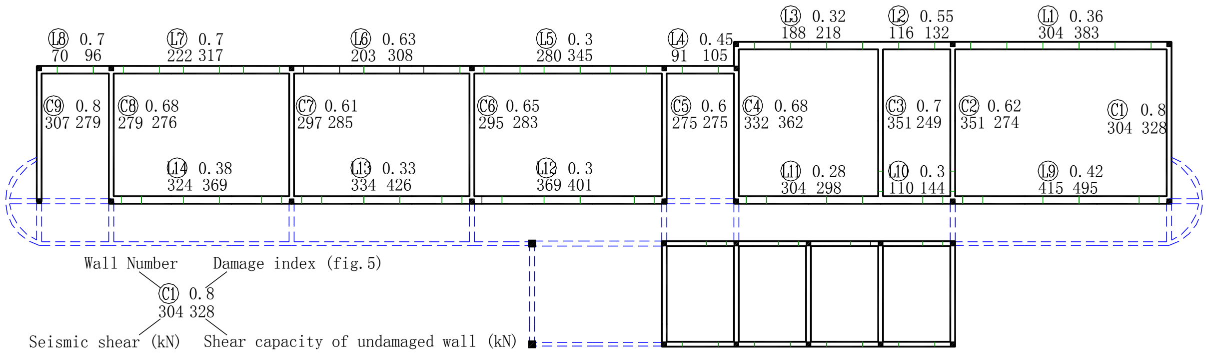


Fig. 4 Damage indexes, Seismic shears and shear capacities of the walls in storey 1

Table 3.1. Damage level and damage index of the masonry walls

Damage level	Ⅳ	Ⅲ	Ⅱ	Ⅰ
Damage phenomena	Visible cracks at the surface of the wall, no significant influence on the bearing capacity of the wall	Obvious cracks on the wall, damage to the shear capacity of the wall	Significant cracks or apparent inclined of the wall. Severely damaged to the shear capacity of the wall	great penetrating cracks on the wall, collapse or on the verge of collapse, no bearing capacity remained
Damage level	Slight Damage	Moderate Damage	Severe Damage	Collapse
Damage index	0.1—0.3	0.3-0.6	0.6-0.9	0.9-1.0

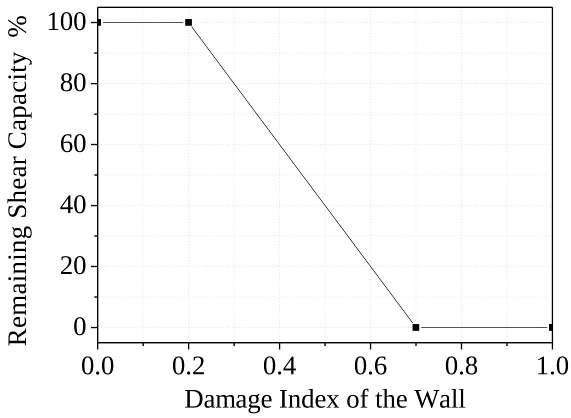


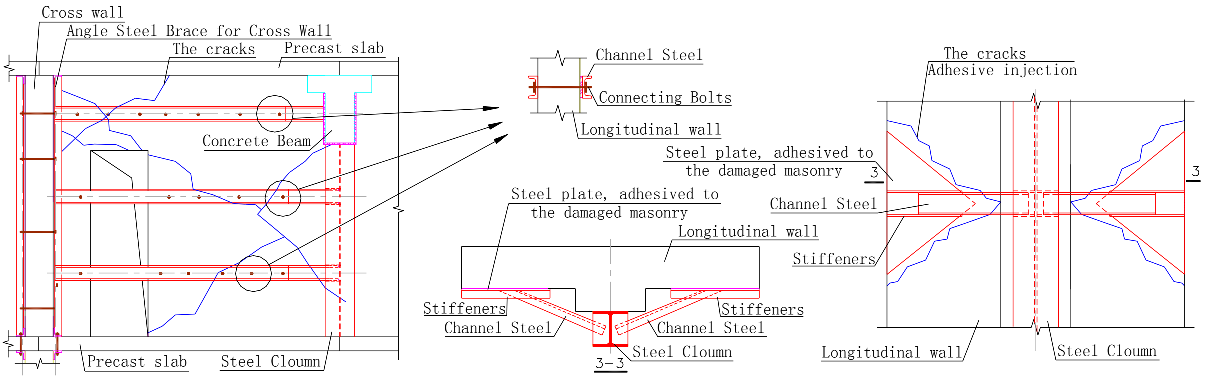
Fig. 5 Relationship between damage index and remaining shear capacity of masonry wall (empirical estimated)

3.4. Connecting measures and retrofit structure system

All the retrofit components, except the longitudinal braces which were not adhere to the masonry walls, were connected to the adjacent masonry walls by expansion bolts, which ensures the retrofit components and the masonry walls working together and making the walls as the anti-buckling support of the steel retrofit components. For several most severely damaged walls, particular constructions are designed to connect them with the retrofit components adjacently. Fig.6 shows the connection constructions of the walls in Fig.1f) and Fig.1g).

Table 3.2. Calculation of damage indexes and shear capacities of several walls of storey 1

Wall Number	Damage Index	Design value of Seismic Shear (kN)	Shear Capacity of Undamaged wall (kN)	Remained Shear Capacity of damaged wall (kN)	Design Value of Retrofit Shear (kN)
C1	0.8	304	328	0	304
C2	0.62	351	274	43.8	307.2
C9	0.8	307	280	0	307
L1	0.36	304	383	260.4	43. 4
L2	0.55	116	132	39. 5	76.4
L12	0.3	369	401	321.2	47.8



a) Construction of the wall in Fig.1 f) b) Construction of wall in Fig.1 g)

Fig. 6 connecting measures

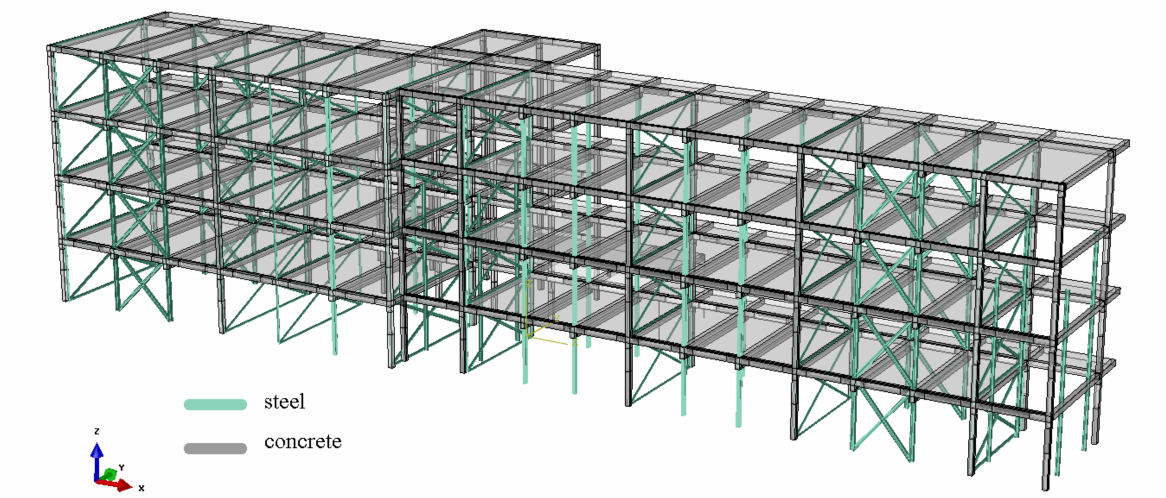


Fig. 7 Sketch of the retrofit structure system

Both the design drawing and investigation shows that almost every masonry wall in every storey was strengthened by cast-in-place reinforced concrete circle beams and cast-in-place reinforced concrete constructional columns around the wall, which integrate all the walls together. Since the earthquake damage investigation shows that there was not very severe damage in circle beams, it can be considered that the circle beams which were casted together with the concrete beams connects the retrofit frames, braces and the masonry walls together, forming a combined structure system composed of braced steel frame, precast concrete slabs and masonry walls, as shown in Fig.7, bearing the possible earthquake action as a whole structure.

4. CONCLUSION

This paper suggest that the basic requirements of protect retrofit of the earthquake damaged building site are reservation of the damage phenomenon, insurance of the vertical load-bearing stability of the site, preventing the site from collapse or local drop under frequent earthquake of design reference period and insurance of the durability of the site.

The retrofit structure type and the design load value should be determined according to the site's damage features and retrofit requirement. The remaining bearing-capacity of the site structure should be reasonable assessment and utilized. Conceptual design and reasonable connections are also important factors for a good protect retrofit design. Constructions for the durability of the site are also need to taken during the protection retrofit design.

Protection retrofit design for the comprehensive building of White Deer middle school of PengZhou, Sichuan province of China is carried out according to the design principles above. Steel components are adopted for the retrofit structure. The remaining bearing-capacities of the walls are estimated by quantifying the seismic damage phenomenon with damage index and evaluating the bearing capacity losing according to the damage index. The retrofit components are connected with the damaged walls by bolts to ensure the retrofit components and the damaged structures carrying loads collaboratively, to prevent the site from collapse or local falling, and to connect all the retrofit components and the site structures into a whole structure, for the purpose of fulfilling the protection retrofit requirement of the earthquake damaged building site.

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